

On Visual Perception of Dynamic Events

by

Sverker Runeson

UPPSALA 1977

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Doctoral dissertation at the Faculty of Social Sciences
University of Uppsala, 1976/1977
ISBN 91-506-0111-3

Abstract

A domain of perceptual functioning, *dynamic event perception*, is identified and a theoretical framework for the study of this domain is developed. The possible existence of information about the dynamic (i.e. causal) properties of objects and events in the optic array is discussed. Linear collisions are analyzed in detail, and it is shown that the kinematics of such events contain unambiguous information about weight ratio and damping factor. Previous research, in particular Michotte's studies of causality perception, is scrutinized with the above as a background and found to have several shortcomings. A distinction between a traditional kinematic approach and a dynamic approach to the study of dynamic event perception is introduced. The dynamic approach is found more appropriate and two paradigmatic experiments are suggested.

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Printed in Sweden by
Offsetcenter AB, Uppsala 1977

ACKNOWLEDGEMENTS

The present doctoral dissertation consists of the three articles referred to as Runeson (1974, 1975, 1976) and of this thesis, On visual perception of dynamic events, which summarizes the three articles. In addition it develops a theoretical framework which, departing from the articles, extends to a delineation of a new field of perceptual research.

Gunnar Johansson has been my supervisor and I am indebted to him for support, advice, and encouragement throughout the work leading up to the present thesis. It was also through acquaintance with his work that I first became aware of perception as an interesting and legitimate field of research, and my appreciation of his approach to the study of perception has undoubtedly had a strong effect on the development of my own approach.

As should be evident from the contents of the present thesis, my approach to perception rests on two more cornerstones. One is provided by James J. Gibson, who has influenced me both through his written works and through the personal contacts I have been fortunate to have with him.

The third cornerstone is provided by Albert Michotte, with whom I am too young to have had personal contact, but whose written works have inspired me both in general and in my work on the particular topic treated here.

In addition, numerous people have contributed scientific, technical, administrative, typographical, and personal support, but I will refrain from trying to enumerate them. My reluctance to do so does not imply that the support thus received has been small, only that I feel incompetent to write in such a way as to preclude the reader's reading between the lines hints about the relative amount and quality of support received from different people. Although the supporters could not possibly have been equal in their contributions (whatever that would mean), it feels neither meaningful nor fair to attempt an evaluation of them, much less to publish such a rankinglist (in any form).

I can only hope, therefore, that my supporters will accept my sincere, but general, expression of gratitude, and that they will not feel offended for not being mentioned explicitly.

Uppsala, March, 1977

Sverker Runeson



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1 MOTION AND EVENTS

Are the "ongoings" of the environment best handled as motions or events? A consideration of the two terms reveals that they are not mutually exclusive but rather belong to different descriptive contexts. In everyday language we usually talk about what happens, making use of a large repertoire of words which stand for different categories of events. Talk about motion and its properties seems to be less common, by and large limited to longlasting and undramatic ongoingings.

On the other hand, when we take an analytic approach, as in scientific mechanics or technology, we seek to get away from the event categories and to handle everything in terms of motion and changes thereof. In that way the laws of motion become applicable, and the possibilities of prediction and manipulation are often improved enormously.

In the scientific endeavour of understanding perception we are interested in the functioning of an existing information-getting system. The issue of motion vs. events must then become an empirical question of how the system in fact works, no matter how fundamental motion descriptions may seem to be in mechanics and technology.

The major contention of the present work is that perception to a large and important extent handles the ongoingings of the environment as events. The events have properties, some of which may be quantitative. It is implied that studies of "pure motion perception" are bound to overlook or misrepresent many fundamental perceptual processes.

A domain of perceptual functioning, called dynamic event perception, will therefore be delimited, and a theoretical framework for the study of it will be developed.

1.1 Studies of motion perception

Although ongoingings are crucial aspects of the world we perceive, studies of perception of changing conditions were for a long time quite rare. There seem to have been both theoretical (motion considered to be a secondary quality, made up of position and time impressions) and practical (lack of appropriate laboratory equipment) reasons for the negligence.

In more recent years there have been studies of ongoingings construed as motion perception, both as phenomena in their own right (e.g. Brown, 1931; Bonnet, 1964; Cohen, 1964; Johansson, 1950a, 1950b; Mashhour, 1964; Svensson, 1971), and in connection with the study of depth perception, where moving and/or changing displays yield superior depth impressions (surveyed by Braunstein, 1976).

1.1.1 Velocity-Seen-as-Such. In the ambition to study the perception of "pure" motion, long and steady motions have been used, sometimes only a flowing regular pattern ("stripes") seen through a window (e.g. Brown, 1931), and starts and stops have been avoided. Alternatively one has used rotations or other longlasting cyclic motions or changes (e.g. Johansson, 1950a, 1950b). Usually one has obtained one judgment, mostly of velocity but sometimes of distance, direction, or duration. The judged property was then related to the corresponding physical property of the motion presented. Implicitly one has assumed that velocity (distance, etc.) is perceived as such. In a few cases such an assumption has also been made explicit (Ogawa & Kusano, 1973; Sjöberg, 1966) as a rationale for advanced computations on obtained data. In studies of thresholds for sudden (Hick, 1950) and smooth changes of velocity (Gottsdanker, 1956) the same assumption has been implicit, i.e. that not only constant but also changing velocity is perceived as such.

Recently, the Velocity-Seen-as-Such assumption has been challenged and shown to be untenable (Runeson, 1974, 1975, 1976). Large discrepancies between physical and perceptual descriptions of motions have been found to exist during what may be called the "start phase" of a movement (tentatively up to half a second). The discrepancies seem to be due to the perceiving of the start phase first of all as an event, which could be of different kinds, be more or less violent, etc. These phenomena will be treated more extensively in section 4.5 below.

Thus, even in studies which explicitly deal with motion perception, the notion of event sometimes becomes unavoidable. For an adequate understanding of the perception of starting movements it therefore seems necessary to study start events qua events: their qualitative and quantitative aspects and the dependence of these on the physical motion functions shown. Once this is realized, we must accept the possibility that other types of motion configurations are also handled in perception as events. A new approach to "motion perception" is thereby suggested.

1.2 Ecological events

Ecological considerations of what there is to be seen in a normal terrestrial environment has also led James J. Gibson to refute "pure motion" as a basis for the study of the perception of what goes on in the environment. Since his work in this area presently exists only as manuscripts, a somewhat extended review will be given. He goes so far as to deny the existence of motion perception (and time perception) and substitutes the perception of (ecological) events.

"Just what are we to mean by an ecological event? Is it possible to define one and to make a sort of classification? No such attempt has ever been written out, so far as I know, but I shall try it. For only if we know what we mean by an event can we describe the change in the ambient optic array that specifies it, and only then can we begin to study the perceiving of it." (Gibson, II)

Gibson suggests a classification into changes of surface layout, changes of surface color and texture, and changes in the existence of surfaces. Changes of layout, which will be of primary interest here, are subdivided in the following way:

"Rigid Translations and Rotations of an Object
 Displacements (falling body, flying arrow)
 Turns (opening door)
 Combinations (rolling ball)
 Non-Rigid Deformations of an Object
 Inanimate (drops of fluid, lumps of clay)
 Animate (change of posture of animal)
 Surface Deformations
 Waves
 Flow
 Elastic or plastic changes
 Surface Disruptions
 Rupturing, cracking
 Disintegration
 Explosion" (Gibson, II)

Commenting on the above suggestive tabulation, Gibson writes:

"It has to do with what might be called ecological mechanics, which is rather different from either celestial mechanics on the one hand or particle mechanics on the other, including thermodynamics. Carpenters and builders are familiar with this branch of physics, although it is not taught in school. The terrestrial substratum is an absolute frame of reference for /these motions/. The world does not move, not at this level of analysis." (Gibson, II)

Summarizing, Gibson writes:

"The foregoing classification is a kind of preliminary survey only. Ecological events are infinitely various and difficult to formalize. But when we attempt to reduce them to elementary physical events, they become impossibly complex, and physical complexity then blinds us to ecological simplicity. For there are regularities to be found at the higher level, regularities that cannot now be encompassed by the simple equations of mechanics and physics. The movements of animals, for example, are lawful in ways that cannot yet be derived from the laws of orthodox mechanics, and perhaps never can be. A too strict adherence to mechanics has hampered the study of terrestrial events." (Gibson, II)

Hence, Gibson's discussion of events seems to be based on a survey of what goes on and happens in a normal environment, combined with the forbidding complexity encountered when standard physical variables are brought to the description thereof.

A potential weakness in Gibson's discussion of events is the absence of criteria for what should belong to the event category and what should not. This might be due to the very preliminary nature of his discussion, but some

passages seem to indicate that, according to Gibson, such criteria should not be sought:

"... the flow of ecological events consists of natural units that are 'nested' within one another. There episodes within episodes, subordinate ones and superordinate ones. What we take to be a unitary episode is therefore a matter of choice and depends on the beginning and the end that are appropriate ..." (Gibson, II)

Among the few properties that Gibson seems to require from an event is that it have a beginning and an end. This requirement, of course, immediately renders Newtonian mechanics less appropriate for the handling of events, since beginnings and ends would have to be described as more or less complicated changes of basic Newtonian variables. Gibson also suggests some quantitative limits for events, but these are wide indeed. Thus, concerning "behavioral events", he suggests that:

"... they are activities of an organism at the ecological level of size and duration, measured in centimeters and seconds, not in microns or miles and not in microseconds or years." (Gibson, II)

Another specification of ecological events is that they be objective:

"... a displacement of the point of observation will be excluded, since it refers to the locomotion of a potential observer not to the motion of a surface. Similarly, the events we are concerned with are terrestrial so that the motion of the sun across the sky will be excluded, together with the peculiar motions of shadows that depend on it. We are interested in events that occur quite independently of where the observer is and where the sun is." (Gibson, II)

To conclude, it seems that Gibson intends (ecological/environmental) events to include everything that goes on in the environment of a terrestrial animal which could also be of some relevance for the animal to perceive. He thereby wants to direct research on perception to more relevant problems and away from basic physical variables which are inappropriate for description of environmental events and therefore have little chance of being fundamental for perception. A new and much more appropriate level and kind of concepts are suggested to replace the scientific ones. Instead of studying motion perception and time perception we are urged to study the perception of events. For this purpose a new physics must be developed for the description of ecological events, and the information available in the optic array for such events must be analyzed.

It is important to note that Gibson's treatment of events is prescriptive in a sense. It prescribes what there is to be seen without "consulting" the perceiving system. In this respect it has a formal similarity to conventional psychophysics, in which the basic variables of scientific physics a priori were taken to be basic perceptual variables. It will be a fundamental postulate in the present work that perception has a descriptive system of its own,

consisting of concepts (categories, variables, properties) in which our perception of the environment is structured. If so, there is no reason to expect the concepts of scientific physics to be equivalent to the perceptual ones since the former were developed for very special purposes (Ruenson, 1974). This is why conventional psychophysics cannot handle essential perceptual problems.

Gibson's ecologically based conceptual structure seems to have much better chances of being appropriate for perception. Yet, because of its prescriptiveness, studies based on it still would run a certain risk of being nonrepresentative of normal perception in the sense that the properties studied might not be those actually "used" by the perceptual system. Following our postulate above, the choice of perceptual properties for study can only be done on empirical grounds. Gibson's discussion of ecological events will undoubtedly be an important source of inspiration in such work.

1.3 Dynamic events

In the present work the term "event" will be used in a more restricted sense. It will be suggested that a class of ongoings, events, can ultimately be distinguished from other ongoings on the basis of differences in the nature of the processes through which they are apprehended. It would be premature to attempt a precise definition of these process differences, but we may assume that they have consequences both phenomenologically and psychophysically. Tentative distinctions in these domains will therefore be attempted below (the psychophysical in section 2.1). Furthermore, distinctions will be attempted in purely physical terms (section 1.3.3) and in terms of the availability of information about certain properties of the objects involved in ongoings (section 2.3). Although the limits will be quite diffuse, it is believed that the delimitation of the concept of event thus achieved is sufficient for a theoretical analysis and a first round of empirical studies of the perception of such events.

1.3.1 Inferred vs. perceived ongoings. Motions like that of the hour-hand of a clock are too slow to be perceived. They can be apprehended only by perceiving positions at two or more instants of time, comparing them, and inferring motion from the differences in position. Such motions are therefore not perceived but apprehended intellectually, and they are not to be considered as events. The growth of plants and animals belong to the same category, although it is a matter of change of size and form rather than motion.

In contrast to inferred ongoings there is a major category of environmental

ongoings which are perceived, i.e. apprehended directly without any interpretation or other intervention of conscious faculties. Only the end products, the percepts, become conscious. This separation of intellectually apprehended ongoingings from those properly perceived is a traditional one in the psychology of perception (Exner, 1875; Johansson, 1970).

1.3.2 Events vs. processes. Our crucial distinction will be made within the field of perceived ongoingings, between events and processes. As examples, consider the bounce of a ball and the rolling of a ball, respectively. On a phenomenological (i.e. intra-perceptual) level there are some obvious differences. The bounce is momentary but the rolling lasts, i.e. has a duration. Prominent features of a bounce are, for instance, the heaviness and "springiness" of the ball, the hardness/softness of the surface, the "strength of blow" dealt by the ball, etc. Prominent features of a ball rolling are instead speed, direction, duration, etc. Note that the latter set of features are rather superficial, whereas the features of the bounce concern factors behind the movements.

1.3.3 Kinematics vs. dynamics. These two sets of features correspond quite precisely to the subdivision of the science of mechanics into kinematics and dynamics. Kinematics refers to the description of motions in geometrical terms, i.e. distances, directions, velocities, accelerations, etc. Dynamics refers to the explanation (prediction) of motions. For that purpose concepts are needed which refer both to properties of the objects themselves (e.g. mass, elasticity, viscosity, friction) and to their motions and interactions (e.g. force, momentum, impulse, moment, energy, power) (Symon, 1960, p. 3). Dynamics is therefore the theory of mechanical causality.

The kinematics vs. dynamics terminology has already been used by Johansson (1970) to distinguish studies of "pure" motion perception from studies in which perceived force is involved, as in perception of causality and free fall. If we take dynamics to stand for causal factors in general, the terminology can also be used to characterize perceived events as opposed to perceived processes. Thus we may say that perceived events are dominated by dynamic properties with kinematic properties weak or absent, whereas processes are predominantly kinematic. For this reason, the term dynamic event will be used to avoid confusion with other uses of "event".

For the purpose of describing what there is to be perceived in the environment, it may be useful to try to make a distinction between dynamic events and processes also in purely physical terms. It cannot be made in any straightforward way, however, since all ongoingings have both kinematic and dynamic properties. Instead we may say that environmental dynamic events are occurrences involving one or more objects (or creatures) and consisting of rather abrupt

changes in the kinematic state of the object(s) resulting from exertion or exchange of energy (or momentum) among the objects. Certain deformations of objects and surfaces due to forces should also be included.

The way that dynamic properties like energy and momentum are involved in processes such as the running of a car or the spinning of a wheel is trivial since the properties in question are more or less constant. A description in kinematic terms is therefore sufficient for most purposes. In dynamic events, on the other hand, there may be dramatic changes in energy consumption or, perhaps more importantly, there is transfer of momentum from one object to another. The objects may be deformed or broken. It is the dramatic dynamic features of events that make them urgent to perceive, and it is mostly the dynamic features which need to be picked up first of all. Or, to put it differently, we need to perceive the dynamics of events because it contains information about the causal relations in what happens. Perception of "causality", as studied by Michotte (1963) and others, would therefore be but a special instance of dynamic event perception.

1.3.4 Scientific dynamics vs. perceptual dynamics. We may say, that we do perceive the dynamics of events, at least to a large extent. Starts, stops, bounces, collisions, catchings, hits, touches, breaks, squeezes, releases, hoists, jumps, etc., are examples of events which are usually distinguished in perception. It is important to note that these categories are not to be found among the concepts of scientific dynamics, i.e. the theory of dynamics that mankind has developed through systematic intellectual endeavours. Nevertheless, they are used to distinguish events which differ essentially in their casual structure. The difference, for instance, between a hit and a touch lies in the amount of momentum transferred. Categories of this kind undoubtedly belong to the field of dynamics.

For each of these event categories we usually also perceive a number of finer characteristics such as the strength of a blow, the heaviness and hardness of the object(s) involved. Despite their quantitative nature, these concepts do not automatically belong to scientific dynamics either, but certainly to the field of dynamics. We may assume that there are relations between perceived event characteristics and scientific dynamic variables which can be discovered.

For the above reasons, it must be accepted that the field of dynamics is covered in perception by a conceptual structure which differs extensively from that of scientific dynamics. We will use the term perceptual dynamics when necessary to emphasize that we are talking about the ways that perception handles dynamics. The problems for the study of dynamic event perception introduced by the discrepancy between scientific and perceptual dynamics will be treated repeatedly below.

2 THE PROBLEM OF DYNAMIC EVENT PERCEPTION

The existence of dynamic event perception poses a problem for psychology: How can we get to know about dynamic properties of events without any contact between the bodies involved and our own body (only visual event perception will be considered)? The dynamic properties in themselves do not cause any transformations or disturbances of the optic array which could constitute information. Since dynamics is the causal properties of events, there remains the possibility that dynamic properties reveal themselves through that which they cause: motions and changes. In other words, there might be information about dynamics in the kinematics of events. Shape and color of objects may also contain cues, at least to the stable properties of the objects. However, information through kinematics seems to be the more promising possibility. It will therefore be the main topic in our analysis.

2.1 The psychophysics of dynamic events

It has been suggested above (section 1.3.3) that dynamic events constitute a discernable category of ongoings, both physically (environmentally) and perceptually. Dynamic events as described by scientific physics are characterized by rather dramatic exertions or exchanges of energy, a small part of which is treated in books on mechanics under the heading of "impulsive motion" (e.g. Smith, 1962, p. 176). As perceived, dynamic events differ from other ongoings by being predominantly dynamic, with kinematic properties weak or absent. From this must follow that the psychophysical relations in dynamic event perception are of a special kind, since they include the indirect ways that information about dynamic properties is contained in kinematics.

When it comes to the psychophysics of processes, on the other hand, the situation is different since both the physical and perceptual descriptions concern kinematic properties. A variable for variable correspondence is therefore possible. It cannot be taken for granted, however, since there might also be discrepancies between perceptual and scientific kinematics (see Runeson, 1974, and section 4.5 below). Nevertheless, the psychophysical relations in the perception of kinematics must be different from, and simpler than, those in dynamic event perception. This difference can be taken as the basis for a psychophysical distinction between events and processes (a phenomenological and a physical distinction was suggested above, section 1.3).

2.2 Dynamic events vs. dynamic properties

The distinction between events and processes might seem to be trivial in a sense, since the percept of an event (and the psychophysical relation) could be

predominantly dynamic only when the real event is in fact rich in dynamic content. Thus there need not be any differences in the kind of perceptual process, only in its content: varying proportions of dynamics and kinematics. We should perhaps better study perception of dynamic properties as a general aspect of perception, along with perception of kinematic and static properties. In fact, it seems to be a general feature of perception that it gets at the sources of motion and change (see for instance Johansson, 1950b, esp. p. 148).

It must be remembered, however, that there are two kinds of dynamic properties: permanent properties of objects (object-dynamics) and fluctuating properties of movements and interactions between objects (event-dynamics) (section 1.3.3). The argument above is relevant only for event-dynamic properties.

Event-dynamic properties are, almost by definition, relevant to perception only in rather dramatic events. Object-dynamic properties, on the other hand, are there all the time and of relevance to perception all the time, and all situations are therefore rich in object-dynamic content. The possibility of perceiving them, however, exists only when the object properties have sufficiently specific influences on the kinematics. Only then can information be available. It will be our main hypothesis (to be analyzed below, section 3), that information about object-dynamic properties is available only in some types of ongoings, mostly dramatic and not too simple. Thus, even if we were to study perception of dynamic properties in general, we would soon find that it occurs only in certain types of ongoings. To call these "dynamic events" and to study "dynamic event perception" would be fully appropriate. The above hypothesis about available information also provides a fourth way of distinguishing between dynamic events and processes.

Another reason for retaining the "dynamic event" concept was discussed above (section 1.3.4). It seems to be a basic feature of perception that it identifies a large number of types of events and perhaps that this categorization is superordinate to the perceiving of dynamic properties. The term "dynamic event" therefore has a phenomenological foundation and could help us avoid premature quantitative studies of dynamic properties.

2.3 The duration of dynamic events

Implicit in our discussion of dynamic events has been the notion that as perceived they have little or no duration proper. Nevertheless, their characteristics must depend quite intimately on the kinematics of the event during some period of time, since the dynamics will typically be specified by changes of kinematic properties, such as direction and velocity of motion. As a guide it will be assumed that the relevant time-span is less than one

second. During the critical period of an event, we may guess, also perception of time is absent or upset (cf. Fraisse, 1963).

Although the suggested time-span is quite narrow, it should not be taken to exclude ongoing such as the walking of a human being. They can probably be treated as repetitive dynamic events, and much of our analysis would thereby be of relevance. In a similar way, there may be chained dynamic events. A wealth of simple mechanical repetitive events have been studied by Johansson (1950b). Although the emphasis was on the perception of kinematic configurations, there is much to suggest that the percepts often had a dynamic aspect. The existence of dynamic properties in the percept, and the existence of information for it in the kinematics, is of course what should determine whether a given repetitive or chained motion configuration is dynamic or not.

2.4 How can dynamic event perception be explained?

One possible way of apprehending dynamic properties might be that certain kinematic features in the optic input get associated with tactile and/or motor experiences. On a later occasion the perception of similar kinematic occurrences, combined with recognition of the objects and/or beings involved, through shape, color, etc., might lead us to remember the dynamic experiences and attribute them to what is seen. Or we might make advanced inferences on obtained kinematic data, using our knowledge of physical laws.

Such empiristic and intellectualistic accounts may be questioned by some empirical examples. Johansson (1973) has shown that less than a dozen spots, representing the movements of the main joints of the human body, are sufficient for a most vivid perception of a moving human being. Not only does one see what the person does in general (walk, dance, climb, bicycle, jump, push-ups) but also things like the quality of his gait, degree of activation, how tough the push-ups are to do, etc. All this is accomplished without any shape information which could lead one to identify or classify the source of the movements and with only minimal information about kinematics. Furthermore, the percept is established in less than a third of a second (Johansson, 1976) and is obtained without any interpretations or other conscious operations.

Michotte (1963) has shown that perception of causal (i.e. dynamic) relations such as pushing, entraining, releasing, etc., can be produced by rather crude simulation and manipulation of simple kinematic variables (Michotte's work will be treated in section 4.1 and 4.2). Other examples could be found in Bozzi (1958, 1959) who studied the conditions for the perception of natural swing of a pendulum and natural sliding down a slope, also by means of crude and abstract simulation.

As a further example, consider slow-motion pictures such as used in TV-

broadcast sports games. Despite that all color and shape information is intact and that the kinematic information is only time-scaled down a bit, the dynamic properties are perceptually very much attenuated in comparison with the normal speed film. It can, for instance, usually be seen whether one player touched another, but it is hard to see whether he also gave him a push. To the extent that the slow motion film helps us to understand the dynamics of the event it seems to result from an intellectual interpretation and to be dependent upon our experience of similar situations (the most relevant of which is probably the normal speed version of the same event seen right before!).

It has also been shown that an observer can set the speed of a projector quite accurately when watching films of sports and other human activities rich in dynamic content (Johansson & Jansson, 1967). We may assume that with a film of ongoing things without much dynamic content, such as cars running along smooth roads, certain machines, etc., it would be more or less impossible to set the speed correctly.

Another relevant example is the short cartoon film made by Heider and Simmel (1944). It consists of a few simple black geometric shapes and a few lines which move around. The film is, of course, ambiguous as to what creatures perform in it (i.e. animals, adults, children) and what the particular social relations among them are, but there is no ambiguity concerning the causal relations in their activities. Thus, one immediately sees who is hunting whom, who hits whom, etc. It is also immediately seen who is aggressive and who is afraid. Moods, intentions, and personality traits therefore seem to be pickupable through direct perception. Since they are not dynamic properties in the mechanical sense, they are outside the scope of the present work, but might be studied in a similar way.

Besides the immediacy of the impressions received from the Heider and Simmel film, their being of perceptual nature is also supported by the fact that knowledge about the artificial nature of the display does not alter the impressions of dynamic relations. In a follow-up study by Shor (1957) preinformation about the character of the figures was given. Preinformation in accordance with the typical spontaneous impression of the film did not make any difference, and reversed preinformation did not lead to a reversal of responses. Although the author concluded that preinformation had an effect -- the differences were statistically significant -- there was no evidence of an effect on the impressions of the film, and the only effect of the strong conflicting information seems to have been to confuse subjects about what to respond.

To summarize, it seems that given only the kinematics of environmental events we often pick up the dynamics involved, and we do so through an im-

mediate, unconscious process, which has all the typical features of perception. Note that nothing is thereby said about whether we are endowed with this ability at birth or whether it is acquired later in life. The only thing suggested is that dynamic events are apprehended through perception, the origin of which is a separate, empirical question.

2.5 Dynamic events vs. ecological optics and affordances

2.5.1 Ecological optics. What is the informational basis for dynamic event perception? More precisely, is there information in the kinematics of an ongoing about its dynamic features? If so, how specific is that information, and what form does it have?

In Gibsonian terms, these questions might perhaps belong to the branch of ecological optics. Note, however, that the questions have a special status in that specificity is postulated for the relation optic array - kinematics, which is the relation normally treated in ecological optics, and concern only the next step from kinematics to dynamics (see section 3.1 below). In his discussion of ecological events Gibson has a section on "The optical information for perceiving events" (Gibson, II). However, it deals exclusively with the way kinematic properties are specified in the optic array; quite logically so, because Gibson's delineation of what constitutes events is essentially in kinematic terms.

2.5.2 Affordances. Dynamic events, as treated here, would perhaps better belong to the section on affordances in Gibson's work (Gibson, III).

"The affordances of the environment are what it offers animals, what it provides or furnishes, for good or ill."

Typical examples are "sit-on-ability" and "eat-ability". Unlike "values" and "meanings", affordances are real, since

"Although an affordance consists of physical properties taken with reference to a certain animal it does not depend on that animal."

"The object offers what it does because it is what it is."

As a more precise definition of affordance, Gibson writes:

"... a combination of chemical or physical or geometrical properties of the environment that is uniquely suited to the nutritive system or the action system or the locomotor system of a given animal."

Since an affordance is a combination of certain physical properties, and since the physical properties are specified in the optic array, there is also information about the affordance in the optic array.

"A compound invariant of optical structure is just another invariant. And a genuinely invariant compound can presumably be detected as a unit without any need to associate the components."

The latter is, of course, Gibson's way of saying that affordances can be per-

ceived directly.

Our "dynamic events" have in common with Gibson's "affordances" their being higher order properties based on static and kinematic properties or, more precisely, on information thereabout. There are, however, several differences which would make dynamic events cumbersome to include among affordances. For example, although dynamic events, such as collisions and hits, and dynamic properties, such as heaviness and strength of blow, are often of relevance for an animal they do not seem to offer anything sufficiently specific. If the concept of affordance is widened to mean everything in the environment which could be relevant for an animal to perceive, structured and described in a way which is economical and appropriate for its needs, dynamic events would of course be included. Although inklings of a widening could be gleaned in Gibson's text, the term "affordance" would seem to lose its aptness in the process.

Quite independently of whether Gibson would prefer to widen the meaning of affordance or not, dynamic events as treated here seem to be compatible with Gibson's theoretical framework in general.

3 THE INFORMATION FOR DYNAMIC EVENT PERCEPTION

3.1 Optic array to kinematics

A complete analysis of the information about dynamic events and their properties would have to start from the optic array. However, the optic array information about spatial layout and kinematics has been treated successfully before in the study of perception. It can therefore be postulated that the optic array contains sufficient information to offer any visive creature the opportunity of veridical perception of the spatial and kinematic properties of the normal environment and what goes on there. The reader is referred to the work of J.J. Gibson (e.g. 1950, 1966, 1968), G. Johansson (1974a, 1974b), and D.N. Lee (1974) for analyses which make the postulate tenable.

Our task is thereby simplified enormously, since we need only concern ourselves with the information about dynamics contained in kinematics. Once such information is shown to exist, we automatically know that it also exists in the optic array and is available for visual perception. Also for the purpose of simulating dynamic events for empirical studies, the relation between kinematics and dynamics is necessary to know.

3.2 Kinematics to dynamics

First, we may observe that on the purely physical level the dynamics of a situation (i.e. masses, forces, momentums, substance characteristics, power sources, friction, etc.) determine the kinematics. Thus we may write:

$$D \rightarrow K$$

Our problem is, however, to find how much of D is specified by K.

A simple example will show that the K to D relation is not necessarily specific: A given force (F) acting upon a given mass (m) uniquely determines its acceleration (a), acceleration being a kinematic property, through the relation

$$a = \frac{F}{m} .$$

A given acceleration, on the other hand, specifies only a certain ratio of force to mass. A ratio of two dynamic properties could also be considered a dynamic property, which might be valuable enough to know, but knowing mass and force separate from each other seems to be more useful.

3.2.1 Start events. The analysis above applies to situations without friction. This is never realized in a normal environment, however. If friction is of a viscous kind, such as air or liquid drag, acceleration will level off after some time according to the equation

$$\frac{dv}{dt} = \frac{F}{m} - \alpha v^2 \quad (\alpha = \text{object and medium drag characteristics})$$

approaching the asymptote

$$v = \sqrt{\frac{F}{\alpha m}}$$

which gives the final velocity.

Also in this case velocity does not uniquely specify any dynamic properties but only a relation among them. If both initial acceleration and final velocity are given, as they are if the start of a constant-force movement in a viscous medium is observed, we also have information about the force/mass ratio and α ($\alpha = a/v^2$). α , however, contains many parameters such as medium viscosity, object frontal area, and an air drag coefficient for the object's shape (Schmitz, 1960). There seems to be no way to separate these factors, given the kinematics of a single motion.

The condition of constant force and viscous friction yield a rather special motion function, and it is reasonable to assume that the kinematics therefore contain information about what kind of starting motion it was. It will be taken as an example of a "natural motion" (Runeson, 1974), which has a "natural start". Perception of start events will be treated below (section 4.5).

3.2.2 The Berkeleyan mistake. If we were to conclude from the foregoing discussion that direct perception of dynamic properties such as mass and force is impossible on the basis of kinematic information alone, it would be a serious mistake, however. It would be a mistake of the same kind as Berkeley's (1709/1948) in his "New theory of vision", where he analyses the possibility of seeing the world in three dimensions. His argument that the distance to a point in space is like a line pointed endwise to the eye, and that there is no representation whatsoever of its length in the fund of the eye is, of course, correct as such. However, it is irrelevant to the problem of depth perception, since depth perception does not occur under the conditions of his example. Relevant conditions are instead a cluttered environment and/or moving observer and/or moving or changing objects; conditions which are satisfied in normal situations. And when these relevant conditions are subjected to geometrical analysis (see references in section 3.1) it turns out that there is an abundance of information for perception of spatial properties.

Applied to the case of dynamic events, the foregoing example will tell us first to try to survey the situations in which dynamic events are normally perceived. Trivial to say, it is only in these cases that we have anything which needs to be explained. Only in these situations should we look for available information about dynamic events, and only concerning those dynamic properties which are actually parts of the corresponding percepts. As mentioned be-

fore (section 1.3.4 and 2.1), the dynamic properties "used" by the perceptual system need not be, and most probably are not, those of scientific physics. Some sort of phenomenology must therefore be a first part of the study.

3.2.3 The lost dimension. The analogy with the study of depth perception might be carried one step further. Although there are many ways of stating the problem of depth perception (or size and shape constancy) it is always in some sense a problem of "the lost dimension" or "one dimension too little". This is so because the optic array has only two dimensions independently of whether we treat it as a projection on a plane, spherical, cylindrical, or other surface, or as a sheaf of directions. For a static monocular observer, the optic array cannot therefore be specific to the threedimensional environment in the strict geometrical sense, i.e. independently of what the environment contains.

The equations given above for acceleration, with or without friction, have a similar structure. Two, or more, dynamic properties combine to determine one, or not so many, kinematic properties. When the relation is reversed, the kinematic property, or properties, specifies only a ratio or other combination of dynamic properties. In depth perception the situation is not hopeless, however, since the optic array can be (and is) structured or modulated, which offers the possibility of multi-variable information transmission. Even in dynamic event perception more complex situations might contain more information.

3.3 Linear collisions

Inspired by the finding that more complex situations yield better information about depth, let us analyse the somewhat more complex dynamic event of linear collision between two bodies. Following Symon (1960), two rules determine what happens. First, the combined momentum of the two bodies is the same before and after the collision, although distributed differently between the objects. Second, the ratio of velocity difference between the two objects after and before collision is constant. The ratio is called the "coefficient of restitution" (Symon, 1960, p. 178) and depends on the material qualities of the objects (elasticity, plasticity, viscosity). It is designated by the letter e , and $e = 1$ means that the collision is perfectly elastic, whereas $e = 0$ means that it is completely inelastic or fully damped. For short e will be called "damping" or the "damping factor".

In accordance with the terminology of Michotte (1963) the two objects in a collision will be designated by the letters A and B. A is the object which initiates the event and bumps into B. For this reason we will also follow Michotte (1963) in calling them the "motor object" and the "projectile" respectively.

3.3.1 Basic collision equations. The velocities of two objects after collision (v_A and v_B) are uniquely determined by their velocities before collision (u_A and u_B), their masses (pM and qM ; $p + q = 1$), and the damping factor (e), according to the equations

$$v_A = q u_B (1+e) + u_A (p - eq)$$

$$v_B = p u_A (1+e) + u_B (q - ep)$$

When one object bumps into a stationary one ($u_B = 0$) the equations reduce to

$$v_A = u_A (p - eq)$$

$$v_B = p u_A (1+e)$$

Reversing the issue, it follows easily from the above equations that the ratio of masses (p or q) and the degree of damping (e), which are the relevant object-dynamic properties, are uniquely determined by the kinematic properties (velocities u_A , u_B , v_A , v_B) through the following equations:

$$e = \frac{v_A - v_B}{u_B - u_A}$$

$$p = \frac{v_B - u_B}{u_A - v_A - u_B + v_B}$$

$$0 \leq e \leq 1; \quad 0 \leq p \leq 1$$

It is important that the kinematics fulfil the restrictions on the damping factor and the p -value; if they don't the event is not a true collision and the equations do not apply.

Contrary to the simple case of a natural start, we have found that the kinematics of a collision contain unambiguous information about basic object-dynamic properties.

3.3.2 Compression. The laws of mechanics employed in the above analysis are, as usual, a bit idealized in that they deal not with what actually happens during the period of contact between the bodies, but only with the conditions before and after, which happens to be sufficiently specific. When dealing with "hard" bodies (elastic or inelastic) this analysis seems to be adequate also for the study of perception since the period of contact is very short and the compression of the bodies is very small. With "soft" objects, however, contact time and compression may be noticeable. Contact time and compression, being kinematic properties determined by the dynamics of the collision, could probably yield additional information, in particular about the material qualities. Analysis and simulation of collisions with compression included will require a set

of more complicated equations, of which the ones given above are special instances.

3.3.3 Friction. For a correct analysis and simulation of normal collisions it is necessary to include friction. In the ideal case, sliding dry friction is constant, i.e. independent of velocity. In that case each of the objects will move a certain distance after collision before stopping, and that distance (d) provides information about the velocity (v) it had immediately after the collision according to the simple formula

$$v = \sqrt{2 \mu d}$$

where μ is the coefficient of friction. Since velocity is a kinematic property which could (or should) be picked up readily by the perceptual system, it is perhaps best to think of the above relation as providing information about the friction coefficient, rewritten as

$$\mu = \frac{v^2}{2d}$$

In practice, however, sliding friction does not quite follow the above simple formula. It is higher at very low velocities, especially when velocity is zero (static friction). Furthermore, if the surfaces are wet or lubricated, friction is lower but increases very much with velocity in a rather complicated way. These deviations from ideal dry friction will not only affect the distances covered by the objects after collision, but also the form of the stopping function, i.e. the course of the decline of velocity. It seems probable that these more complicated stopping functions provide additional information about the characteristics of the surfaces.

3.4 Human motion and events

An important category of events of relevance for an animal to perceive are those involving other living creatures. An analysis of such events is therefore needed, but the much higher complexity will presently force us to do it in rather general terms. Although the analysis will concern human motion, it will be generally applicable to much of other animate motion.

The various parts of the human body all have a certain mass, and the ratios of these masses to each other can be taken as rather constant from one person to another. Furthermore, each of the major parts of the body can be treated as rigid in an analysis of movements, and the joints connecting them can be treated as hinges with one or two dimensions of freedom. The position of the center of gravity in each major part is also rather constant ($\pm 5-10\%$) (Bernstein, 1967, p. 9ff).

These features together define a system of complex pendulums. If free to

move, this system behaves in a standardized and, because of the high complexity, highly characteristic way. The effect of the musculature and its innervation is of course to enforce movements other than the natural swinging ones, but for two reasons these effects are limited. First, the strength of the muscles is rather limited in relation to the masses of the body parts. Also, the angular momentum at a joint resulting from a certain applied muscular force is very much dependent on the momentary angle at the joint. The muscular force available is also rate-limited, i.e. decreases with contraction velocity. Together, these factors put severe restrictions on what movements can be performed and what motion patterns can occur (Bernstein, 1967, ch. II).

Second, in reasonably normal motor behavior only a rather small fraction of available muscular strength is used. This is so because our movements tend to agree as much as possible with the free swing pattern. The role of the musculature and innervation is thereby reduced to the production of the difference between a free swing movement and the intended movement. Such motions could therefore be considered as forced complex pendulum motions. The most economic way of forcing a pendulum to attain a certain goal (such as the placement of the foot at a certain spot at a certain instant while walking) is, of course, to modify its phase. The earlier the modification begins, the less effort is required, and the less will the resulting movements deviate from the free movement pattern. The effect of practice on motor behavior can be said to be a modification of the motion pattern to better agreement with natural swing movements of the body parts. For certain primitive motor activities, such as walking and running, which have emerged through evolution together with the shape of our body, a very high degree of correspondence with the natural swing pattern can be assumed.

For reasonably normal activity the kinematics should contain rich information about what a person is doing. In particular there should be information about disturbances or changes in an ongoing activity, both of internal origin, such as change of goal or intent, and external, such as being hit by something or bumping into obstacles.

Already because a change of motion state must by necessity occur gradually, and therefore takes time, it should be possible to obtain a minimum of pre-warning when a person begins or changes an activity. In the case of well practised activities the possibilities for preinformation should be even better, since the more economical way to change activity is usually to begin early.

As an example of a case where free swing movements are not involved, consider the event of hitting a tabletop with the fist as opposed to a similar movement which is stopped by muscular effort right before touching the tabletop. Dynamically the difference between these two cases is, of course,

dramatic. In the hit case all (or most) of the momentum held by the moving hand is transferred to the table where it produces only negligible motion if the table is reasonably rigid and/or heavy. In a false hit the momentum is instead transferred by the muscular stopping effort to the rest of the body via the upper arm and shoulder and then to the substratum (chair-seat or floor). The travel of momentum through the body creates characteristic movements, often called recoils. Thus, the dynamic difference between a true and a false hit is specified in the kinematics. The difference is further enhanced because of limitations in muscular strength and control which prevents the false hit from being as abrupt as the true hit and also produces a small rebound or oscillatory motion of the hand.

Similar arguments would apply to a fistfight situation, although the difference between a true and a false hit should be even better specified in the kinematics because a considerable backward motion should ensue in the recipient of the stroke in the true hit case.

Perhaps more obvious should be the difference between a true hit and a true (i.e. unintended) miss in striking behavior. In a miss one does not get the reactive impulse from the recipient of the blow for which one was prepared muscularily and posturally, and, unlike the false hit situation, measures to stop the forward motion can be undertaken only after the miss has been experienced.

3.4.1 Conjuring. In this context it might be interesting to consider the tricks of a conjurer. Although a variety of methods are employed, an important component in some such tricks is what may be called false motor behavior, i.e. producing the kinematics of one action while in fact (i.e. dynamically) performing another action or none at all (the same is probably true for the pantomime). According to the above analysis such false behavior should be difficult indeed to produce, and the considerable amounts of talent and practice typically required in conjuring supports the idea. Two considerations makes conjuring seem somewhat less impossible, however. As noted above, normal motor activity requires only a small amount of our available muscular force. Thus, there is force available for overriding the normal correlation between the dynamics and kinematics of a movement. To use this spare force without also displaying the characteristic kinematics of high-force movements, it is necessary to control the force more accurately than normally and to prevent the recoils from producing visible auxiliary movements. Recoils consist of momentum, which according to Newton's Second Law is indestructible. It can be transferred from one object to another, or from one part of the body to another, however, and visually it can be said to disappear when it is transferred to a mass large enough to make the resulting movement negligible. A firm support

is equivalent to a large mass, and having an unusual or concealed support would seem to be one way of avoiding disclosing recoils.

A second consideration is that false behavior must agree with real behavior only to the extent that their kinematics be indiscriminable in visual perception. The perceptual mechanisms can be assumed to utilize only some of the available information, and to do so according to rather idiosyncratic principles not primarily geared to the discrimination of false from true behavior. Just as it is possible to fool the visual sense about the spatial properties of objects through special arrangements, it should be possible to fool it about dynamic properties if deliberate and skilled attempts are made.

The conclusion to be drawn for the study of perception is that, since so much of talent, know-how, and practice is required for conjuring, the dynamics of human motor activity must be specified in the kinematics to a rather high degree, and the visual sense must also make rather good use of it.

3.4.2 Inborn or learned ability? Once again, let us point out that nothing is said in the above discussion about whether our ability to utilize this information is inborn or acquired through individual experience. However, since the cases analyzed are characterized by an interplay of eternal physical laws and the evolution-old properties of the human body, inborn mechanisms for dynamic event perception are both possible and reasonable to assume. In any case, the mechanisms are not easily altered, since the tricks of a good conjurer often work just as well when the observer knows all about how they are in fact done (see Michotte, 1955, for a discussion of conjuring effects).

4 STUDIES OF PERCEIVED DYNAMIC EVENTS

4.1 Michotte's studies of the perception of causality

Of the studies relevant to dynamic event perception the major work is undoubtedly Albert Michotte's "La perception de la causalité", which appeared in 1946. An extended version in English was published in 1963: "The perception of causality".

Michotte's point of departure was the fact that we sometimes say that we "know", "understand", or "infer" what was the cause of some event, whereas sometimes we "see", for instance, one movement cause another movement. And we "see this as clearly and immediately as in other circumstances /we/ see two moving objects passing or overtaking one another" (Michotte, 1963, p. 349).

His main purpose was therefore to

"... obtain more precise information as to the conditions in which observers find it necessary to use these terms, and ... to reach some understanding of why they speak, in one form or another, of 'knowing' in the first case and of 'seeing' in the second" (Michotte, 1963, p. 349).

Since his experiments count well over a hundred it is beyond the scope of the present work to give an exhausting review, but a few type cases will be described.

Launching: One rectangle (A) moves toward a stationary one (B). A stops when it reaches B, and at the same time B starts to move away from A with the same or lower velocity. The impression of this event is clearly that A bumps into B and sends it off.

Entraining: As in the launching case, but instead of stopping, A continues to move together with B. The impression here is that A "takes along" B.

In both these cases one clearly sees that A causes B's movement, and that all of B's movement is due to the encounter with A. This, according to Michotte, is the genuine form of causal impression, as opposed to the following:

Triggering: As in the launching case, but B's velocity is higher than A's. The impression is that A triggers or releases B and thus causes B's movement in the sense of initiating it, but at least part of B's movement is due to the activity of B itself or some invisible agent. This kind of causality is therefore of a different kind.

4.1.1 Explanation of causality percepts. Michotte's ambition, as indicated above, has not only been to establish under which stimulus conditions the various types of causal impressions occur, but also to reach some sort of explanation or understanding of why they occur. In order to do so, he first introduced the concept of "ampliation of movement", meaning the extension of motion from one object to another (Michotte, 1963, chap. XIV). Ampliation was

thus necessary for true causal impressions to occur. In a later version of the theory, Michotte has analyzed the causal impression further (1963, pp. 313-352). The typical launching situation contains only two phases, kinematically speaking: A's movement up to the stationary B, and B's movement away from the stationary A. Phenomenally, however, there is a third phase interpolated between those two, and it is this middle phase which is crucial for the causal percept. The middle phase, according to Michotte, occurs because there is a conflict between a perceptual tendency towards continuation of the kinematic state of the first phase, i.e. A moving -- B at rest, and the change of the stimulus conditions which occurs at the moment of contact. This conflict is perceptually "solved" through a "phenomenal duplication" of B's movement. Thus, during the middle phase, B is executing A's movement while at the same time undergoing passive displacement. During the middle phase, which seems to last between a fifth and a third of a second, B does not have a movement of its own but only prolongates A's movement.

In the entraining case a similar analysis is applied, but here the last stage consists of A and B forming a unit with a common motion according to the Gestalt law of common fate. In analogy with the launching case, it takes some time of common motion before the AB-unit is formed and during this intermediate phase the physical motion of B is again phenomenally duplicated.

To sum up, Michotte has attempted to explain the causal impression by showing it to be constituted by well-known Gestalt-type perceptual tendencies or principles.

4.1.2 Negative and paradoxical cases. Michotte sometimes showed stimulus arrangements which were supposed to picture real causal events, but nevertheless failed to elicit causal percepts. These are called negative cases. Paradoxical cases, on the other hand, are those where causal impressions are obtained despite the stimulus conditions being impossible as representations of real causal events. The occurrence of such phenomena has an important role in Michotte's discussion, since it provides an indirect support for the genuinely perceptual nature of the causal impressions. The causal impressions do not seem to be based on acquired knowledge or expectations, and therefore were taken to support a nativistic standpoint as to the origin of the perception of causality (Michotte, 1963, p. 109).

4.2 Critique of Michotte's work on causality

The concept of dynamic event perception, as treated here, together with the embryonic ecological and mechanical analyses of the information about dynamics available in kinematics, can be used to pinpoint some weaknesses and limi-

tations in Michotte's work. It will be done through considering it as studies of dynamic event perception, an attitude which is somewhat different from Michotte's own.

As mentioned above, Michotte sought to reach an understanding of the causal impressions by referring to known Gestalt Laws and similar principles. These are typically in the form of "tendencies" etc. on a phenomenological level, or they have at most a rudimentary psychophysical reference. It will be maintained here that this is not sufficient to provide an explanation or understanding of the causal impressions (cf. the discussion by Oldfield in the foreword to Michotte, 1963, p. viii). It is by and large only a way of describing the results and what is lacking is a consideration of the mechanical and ecological aspects. One would like to know how we perceive a sample of collision events which is representative, mechanically and ecologically, of real events. One would also like to know what information is available in the kinematics of these events and to what extent and how it is utilized by the visual system.

4.2.1 Representativeness of the launching cases. The analysis above (section 3.3.1) showed that there exist unambiguous relations between dynamic and kinematic properties in linear collisions. In particular, it is possible to take a given kinematic configuration (i.e. four velocities) and test whether it could have been a true collision without external influences, and if so, to calculate what weights the objects had relative to each other and how much damping there was in the materials.

In this light, it is obvious that Michotte's studies concern only some very special instances of collision events, primarily those in which both B's initial velocity (u_B) and A's final velocity (v_A) are zero. The first restriction could be warranted for ecological reasons, since collisions with stationary objects are normal. That the motor object (A) should come precisely to a halt at the impact ($v_A = 0$) is unlikely, however. It occurs only as a special case when the damping factor (e) happens to be equal to the weight ratio:

$$e = \frac{m_A}{m_B} = \frac{p}{q}$$

The situation is illustrated in Figure 1. The non-shaded area represents the "linear impact space", within which all true linear collisions must fall. The damping factor (e) is sharply limited between zero and one, with sandbags and steel balls as examples close to the extremes. The horizontal axis is the mass ratio, which theoretically could vary from zero to infinity, but which for our purposes could be roughly limited to, say 1/100 - 100/1. The above-mentioned special case is represented by the "launching" curve, and almost all of Michotte's launching experiments fall on the solid part of the curve.

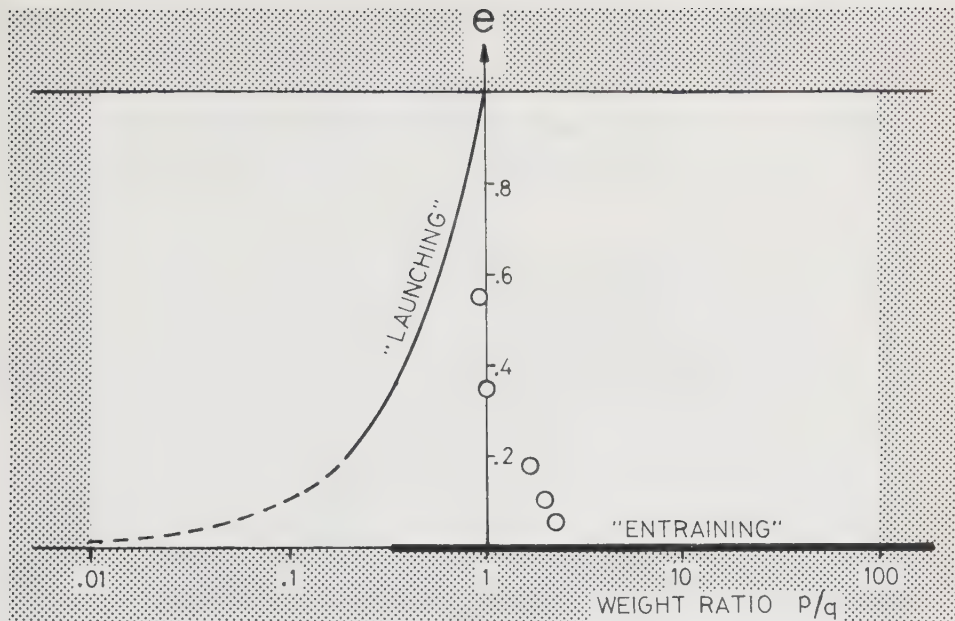


Figure 1. The "linear impact space" with Michotte's (1963) launching and entraining conditions indicated.

The consequences are at least twofold. One is that since $0 \leq e \leq 1$, and thus $m_A \leq m_B$, the motor object is represented only as equal to, or lighter than, the projectile. That is a non-ecological restriction, of course. Furthermore, Michotte's experimental conditions require a covariation between damping and weights of the two objects. That is also a non-ecological restriction, since damping properties and weight are independent but permanent features of each object, and collisions could occur between any two objects.

There seems to be only one relevant experiment in which Michotte (1963) has departed from the special case of no motion in the motor object after impact (Exp. 18, p. 71). The motor object was allowed to continue at five different forward velocities, and the positions of these cases in the linear impact space are indicated by the circles in Figure 1. Michotte's reasons for trying these cases have nothing to do with mechanical considerations, and despite the additions the representativeness of the launching cases remains low.

It therefore seems warranted to say that Michotte has missed a fundamental property of real collisions: that the motor object still has a certain motion after the impact -- forwards or backwards depending, in a purely quantitative way, on the circumstances. Each of Michotte's launching cases taken alone is, of course, a fully possible one but as a family of launchings they are weird and certainly not representative.

4.2.2 Representativeness of the entraining cases. Michotte's second category of causal percepts, entraining, is also a linear collision, mechanically speaking. It is characterized by A and B having the same velocity after impact ($v_A = v_B$), which corresponds to a case of complete damping ($e = 0$). It could occur, for instance, when one or both of the objects is like a piece of wet clay or a sandbag. So far it is an ecologically reasonable case, but in the type experiment the motor object (A) does not lose any velocity at all ($v_A = v_B = u_A$). Mechanically, this requires that the weight of the projectile (B) is negligibly low compared to that of the motor object. This is not entirely unreasonable: think of a car "bumping into" a falling leaf!

Although this was the type experiment, Michotte also tried one case in which velocity dropped to one quarter upon impact (1963, p. 158f). It corresponds to a reversed and more balanced weight ratio: the projectile threetimes heavier than the motor object. In passing (p. 159) Michotte also mentions that he has tried velocity ratios of 10 to 1 or more and found that the causal impression disappears (to be discussed below, section 4.2.5). The positions of the entraining cases in the linear impact space are indicated in Figure 1.

Together, the launching and entraining cases cover a rather small part of the linear impact space. In addition, there are a number of experiments which do not fit into the linear impact space because they imply values of the damping factor (e) or the weight proportions (p or q) outside the permissible ranges and therefore could not represent real collisions. In some such cases causal impressions of launching or entraining were nevertheless obtained (e.g. Exp. 17, where $e > 1$, and Exp. 55, where $p < 0$). Thus our mechanical analysis reveals that the number of paradoxical cases is larger than Michotte himself thought. (However, some of his paradoxical cases will be disputed below; section 4.2.6.)

The lack of ecological representativeness in Michotte's experiments can be said to depend on his manipulation of the resulting (kinematic) properties instead of the causal (dynamic) properties. This distinction suggests two alternative approaches to the study of dynamic event perception, which will be discussed in section 5.1.

4.2.3 Michotte's references to mechanics. References to mechanics, i.e. to the circumstances of real events, are very rare in Michotte's work. When they occur they are kept at a footnote level, as it were (e.g. Michotte, 1963, p. 111f, 226f), and considerations of mechanics seldom if ever seem to have been allowed to influence his choice of stimulus conditions. However, it is hard to believe that he has manipulated the conditions in a purely haphazard way in search for those that would yield interesting impressions. More probably he has been led by intuitive ideas of mechanics, which could, of course, be useful,

at least on a qualitative level, but bringing in some scientific mechanics could certainly help avoid many pitfalls.

An example of Michotte's "footnoteish" references to mechanics can be found on page 111f. After having described an experiment where the launching impression was shown to give way to triggering when the velocity of the projectile (B) is raised to about twice that of the motor object (A), Michotte adds the following footnote:

"... it is interesting to note that, according to the laws of mechanics, if the bodies are perfectly elastic, the speed of the body struck can never be more than double that of the body which does the striking ... This limit in fact agrees very well with that of the launching impression as found by our experienced observers, ... Here as in many other perceptual fields there seems to be a curious agreement between the operation of the laws of perception and that of the laws governing the physical world" (Michotte, 1963, p. 111f).

It is true that the projectile can only get twice the velocity of the motor object, but that occurs only if the motor object continues at its original speed after impact. The velocity difference can never increase in a linear collision. Michotte's claim that his result agrees with mechanics is therefore in error, since the motor object always stopped upon impact in his launching experiments.

The reasons for the lack of ecological representativeness in Michotte's work, and the scanty and sometimes faulty references to mechanics, are easy to see. The main aim of his work was not to study the perception of events, i.e. to study how we perceive the causal aspects of what happens in the world around us. Instead he wanted to study the "causal impression" (Michotte, 1963, p. 15), a particular kind of percept which is distinguished from, for instance, "activity" (pp. 18-26) and "dependence" (pp. 358-369). (In a footnote Michotte, 1963, p. 15, admits that the title of his book might be misleading and that he therefore prefers the phrase "causal impression".) Although he sought the relations to the kinematic properties of his displays, relations to the events of the real world have no constituent role in the theory and are discussed in very loose terms (e.g. pp. 224-228).

4.2.4 The concept of cause. When seen from the vantage point of the dynamic event conception, Michotte's work seems to suffer from what may be called a "causality obsession". It seems to derive from philosophical struggles concerning the nature of physical causation and whether it is possible to perceive causation. The dominant view stems from Hume, who claims that we cannot see one object cause the movement of another; only the succession of movements can be perceived. Michotte disagreed with Hume and others on this, and a major aim of his was to provide experimental support for the opposite view (pp. 6-15). Although quite apt for its purpose, Michotte's work is therefore very

narrow in scope when considered as a study of dynamic event perception.

The crucial point seems to be the status of the concept of "cause" (causality, causation). It will be suggested that in the perception of events, "cause" does not have any clearcut meaning just like "cause" does not have a clearcut meaning in mechanics. In the latter case we have instead a whole theory, called dynamics, consisting of several concepts (mass, force, momentum, elasticity, viscosity, etc.) and a set of equations for their application, which together cover the causal aspects of mechanical events (i.e. a theory of mechanical causality). To talk about the cause of an event is therefore quite pointless. Yet it could of course be different in the perception of events, such that in most cases there would be a salient causal factor dominating the percept. This does not seem to be the case, however. In fact there are many examples in Michotte's work to the contrary.

4.2.5 The content of "causal" and "noncausal" percepts. Even in the purest cases of what Michotte calls causal impressions the identification of causation is done by the experimenter through interpretation of the observer's verbal responses to the question, "Say simply what is going on in the apparatus" (Michotte, 1963, p. 305). A typical answer in the launching cases is, "A bumps into B and sets it in motion". Often, in particular when conditions are varied, observers add comments about the finer aspects of the collision, either directly by talking about things like the strength of the blow or indirectly by referring to living creatures, thus making use of the descriptive richness of animistic language. From all these data, Michotte abstracts only one piece of information: "causal impression" vs. "no causal impression". What is thereby lost is a number of dynamic features which were part of the observer's perception of the event. When studying dynamic event perception these features should of course be of primary interest.

Good examples can be found among Michotte's "noncausal" cases, for instance when the motor object (A) bumps into another object (B) which nevertheless remains motionless. The impression reported is that "A strikes B" or that "A hammers B" when the movement is recurrent (1963, pp. 23, 44). Although Michotte admits that these are impressions of "activity", there is no question of causality since:

"... there cannot be any causal impression in cases where one of the two objects is static." (p. 218)

Thus, Michotte's very narrow and special definition of the causal impression excludes cases which seem to be adequately perceived. If asked, for instance, why A stopped, the observer would probably answer that it was because of B: its being very heavy or fixed to the ground. This amounts to saying that the observer is likely to have correctly perceived the essential causal, i.e.

dynamic, features of the event, and what more could we ask for a causal impression? Because the events of the world are different, event perception must also vary in some sort of correspondence with them, otherwise it is not perception at all.

As a further example, take the entraining effect, which according to Michotte is optimal when the AB-unit has the same velocity as A had. When the speed of AB is lowered (to 25%):

"... there is the impression that A deals B a blow at the point of impact, and this impression is the more marked the greater the difference between the speeds; the Entraining Effect then seems more like a 'push'. A greater difference still, ... (a ratio of 10 to 1 or more), has a segregative influence, ... and divides the phenomenon into the two independent phases -- the blow dealt to B by A and the movement of the rectangular block /AB/. In this case the causal impression disappears" (Michotte, 1963, p. 159).

It is, of course, in agreement with mechanics that A deals a blow to B when the AB velocity is lowered. On the other hand, the segregation of the two movements in the extreme case might seem to be a discrepancy between perception and mechanics. It is not so, however, since the kinematic stimulus event that Michotte presents (Exp. 54) is not a correct simulation of any realistic collision event. The error lies in letting AB continue to move slowly a long time and distance after impact. In a real situation there is always friction, and therefore a slow movement quickly comes to a halt, unless it has a means of propulsion built in. And that propulsion must have been off until the impact occurred, since B was motionless at first. Thus, a real situation giving the kinematics of Michotte's experiment must consist of two quite unrelated phases. The percepts reported therefore seem appropriate even in this case, including the fact that AB's motion is caused by something other than A's motion. Thus, it seems to be a good example of well functioning causality perception despite Michotte's declaration that the causal impression has disappeared.

4.2.6 Negative and paradoxical cases are defined by reference to mechanics and might need to be checked. A central example of a paradoxical case is, for Michotte, that the strength of the causal impression is heightened when the velocity that the projectile gets in the collision is lower than the velocity the motor object had before it bumped into the projectile (Michotte, 1963, pp. 109, 220). That is said to be at odds with mechanics since the "efficiency" of A's impact must be higher the higher the velocity produced in B.

Michotte's argument obviously rests on the implicit assumption that the mass of the projectile (B) is taken to be constant through the experimental conditions, conceivably because of the invariant size of the rectangle shown. However, in the environment there exists at most a very weak correlation between size and mass, and size should therefore be a very weak cue to mass.

More importantly, the mechanical analysis of linear collisions presented above shows that the ratio of masses between the two objects is uniquely specified by the kinematics of the event. Thus, whatever cues to mass there might be in size or other factors, they are overruled by the unambiguous kinematic information. When he varied the relative velocities, Michotte therefore also gave information about a change of the masses of the two objects. Michotte's argument for the paradoxicalness of this result is therefore invalid.

We must then ask anew whether in fact the observed increase of "strength of blow" with decreased projectile velocity agrees with mechanics or not. Intuitively, it is quite easy to understand that it does. Imagine, for instance, two identical boxes, one of which is empty and one of which is filled with sand. If one were to kick the boxes, one at a time, with equal effort of the leg, certainly the empty one would move off faster than the filled one. Nevertheless, one would be painfully aware that the "strength of blow" was higher when kicking the filled one. The moral of the example is that the resistance (inertia) offered by the receiver is a crucial factor in the strength of a blow.

The above arguments should suffice to show that there is nothing paradoxical in this "paradoxical case" but instead something quite reasonable. That is as far as one can go with this example -- a stricter mechanical analysis is out of question since the term strength of blow can not a priori be identified with any one mechanical concept or combination of concepts. Instead it turns into an empirical question, that of finding the relation between "strength of blow", which might be a basic concept in perceptual dynamics, and the concepts of scientific mechanics.

Michotte's own experiments, unfortunately, could not be used for the purpose because of their intimate confounding of the mass ratio and the damping characteristics. A systematic study is therefore required. That "strength of blow" should increase with the weight of the projectile is a quite safe assumption, but the effect of the damping factor is hard to guess (section 5.4).

Another major example of a paradoxical case is when both A and B are moving in the same direction but B is slower than A. When A reaches B both slow down. The impression is nevertheless that A caused the slowdown of B. Michotte cannot understand how a push from A could cause B to slow down and declares the case paradoxical (1963, pp. 71, 220). Once again Michotte bases his analysis on a too simplistic mechanical analysis. Here he has implicitly assumed that his stimulus will be taken to be a linear collision, despite that he knows that it could not be so, mechanically. After all, most events around us are not pure linear collisions and perception must handle the other cases too. When the kinematics exclude simple linear collision there is often concomitant infor-

mation about what other kind of event it is. In the present example the temporal coincidence of A reaching B and the slowdown seem to suffice for the perceiving of A as the cause. The fact that B slowed down instead of sped up contains some information about the nature of the objects and what happened when they got into contact. For instance, when a fast car bumps into the back of a slower car both are likely to slow down and stop, either because they were damaged or the drivers apply the brakes. But certainly it was A's bumping into B that caused the slowdown!

One of Michotte's "negative cases" has already been discussed above, A bumping into an immobile B, where we have seen that the percept is quite adequate. Other examples of his are:

"... impressions of attraction, repulsion, or active resistance ..."
(Michotte, 1963, p. 219).

Michotte's troubles with these cases seem to derive from his very narrow definition of the "causal impression" and it is fully possible that these types of events can be perceived appropriately.

4.2.7 On the critique of Michotte's experimental methods. A vigorous criticism of Michotte's experimental methods has recently been published by Joynson (1971) and commented by Boyle (1972) and Montpellier and Nuttin (1973). The most crucial issue is Michotte's frequent use of trained observers and possibly suggestive procedures. This might have concealed individual differences and effects of experience and led to false conclusions about the universality of the causal percepts. Some other investigators have found figures ranging from 80% (Crabbé, 1967, cited by Montpellier & Nuttin, 1973) via 50% (Boyle, 1960) down to about one third (Beasley, 1968) for the proportion of naive observers who get the basic causal percepts.

It is beyond the scope of the present work to go into the details of the dispute. However, studies of dynamic event perception, following the present theoretical framework, will probably have similarities to the work of Michotte. With Michotte is shared the idea that the spatio-temporal configurations, i.e. the kinematics, themselves lead to the percepts of interest independently of what the observer thinks or knows about it (Michotte, 1963, p. 349). From this follows that one will often attempt to present pure kinematics, with other cues to what might cause the movements removed as far as possible, and to obtain reports of some kind about the observers' impressions. If the rather low universality suggested by some of the abovementioned studies were true for Michotte's phenomena it might also turn out to be so in studies of dynamic event perception, and that would weaken the approach.

For two sorts of reasons a suggestion will be ventured, that figures of 33% or 50% or even 80% for the universality of Michotte's phenomena are spuriously

low, at least when brought to bear on dynamic event perception properly studied. The first reason has already been treated above (section 4.2.1 and 4.2.2), namely the lack of ecological representativeness in the motion conditions studied by Michotte. Considered as simulations of real collision events they were bad even in the crucial kinematic aspect. In particular, the motor object ought to have a natural start and should not generally stop at the impact but continue to move more or less in either direction. Also, both objects should slow down and stop sooner or later because of friction. A realistic and representative choice of conditions ought to have much better chances of producing unambiguous causality percepts.

4.2.8 The disc method. The second reason has to do with Michotte's (1963) apparatus, "the disc method" (pp. 27-34). The devisal of this apparatus has received much praise, and considering its flexibility and low price in relation to the resources at the time the praise seems warranted. Johansson (1970) has pointed to the crudeness of the device, and despite Michotte's claims to the contrary (1963, p. 83) it must be assumed that the displays fell short of containing only pure kinematics. They were abstract only in the sense that a number of cues which exist in a real life situation (size, familiarity of object, material) were removed. However, it must have been obvious or even striking to most observers that these were neither real objects nor real collisions, not even real motions. Thus the removal of "positive", non-kinematic, cues was accompanied by the introduction of many "negative" cues, conflicting with the information in the kinematics. It is therefore conceivable that the conflicting cues to some observers were so conspicuous as to preclude the occurrence of the percepts which the kinematics would normally lead to. It would therefore take a certain attitude to disregard the negative cues and open oneself to the perceptual effects of the kinematics, and the experienced observers might have differed from the naive ones primarily in their willingness and ability to assume such an attitude.

It is therefore a bit surprising to find, decades of technological development later, that the disc method is still in use in studies of perceived causality (e.g. Boyle, 1960; Hindmarch, 1973; Natsoulas, 1960, 1961; Piaget, & Lambercier, 1958). It is as though the ingenuity of the disc method has been taken to extend beyond the practical and pecuniary spheres and perhaps to be part of the theory itself! (Some textbooks spend more space to describe the apparatus than the total of stimuli, results, and conclusions (e.g. Hochberg, 1971, p. 524 f).) In some cases, animated film technique has been employed (Crabbé, 1967, cited by Montpellier & Nuttin, 1973; Beasley, 1968) and Michotte himself sometimes used a "projection method" (1963, pp. 34-40). Although the quality could vary considerably, it should be clear that even with meticulous

care, these kinds of displays also have many shortcomings, for instance, in terms of blur, flicker, and instability of image. Thus, they are open to the same criticism as the disc method. With modern electronic and optic methods it is possible to achieve much better simulations of the kinematics of collision events, and to give the display a touch of realism without introducing any non-kinematic cues to the nature of the event simulated.

It is suggested that with proper use of such techniques and representative choice of collision conditions (see Figure 1) the proportion of observers who do not get spontaneous impressions of causality will drop considerably. (The author has some preliminary empirical results to support the suggestion.) If this turns out to be true, it will imply that Michotte's results, or at least some of them, are representative of normal perception, and his use of experienced observers will appear to have been a risky but necessary way to get around the shortcomings of the apparatus

4.2.9 On the value of Michotte's work. Our analysis of Michotte's studies of perceived causality has shown it to have a number of shortcomings when considered as studies of dynamic event perception. This must not blind us to the great positive value these studies have, nevertheless. Two of its many contributions will be mentioned here because of their importance for future studies of dynamic event perception.

First, Michotte has, in fulfilment of his main purpose, shown that causal relations can be perceived. Thereby he has pointed out that perception has a much more delicate role in human information processing than commonly assumed (Michotte, 1963, e.g. p. 349). He has shown that causal percepts can occur under conditions of quite crude kinematic simulation, which indicates that crucial mechanisms of dynamic event perception can be studied without bringing all the complexities of normal situations into the experiments, Michotte has also illuminated the relation between perception and cognition; an issue which has important methodological consequences for the study of perception, and is of general relevance for many other problem areas in psychology and philosophy (Michotte, 1963, pp. 199, 270f, 311f; see also Michotte's articles of 1948, 1955, and 1959).

Second, the wealth of empirical material in Michotte's work should be an important source of starting points and inspiration in studies of dynamic event perception. Beside the large body of collision studies, there are pioneering experiments on many other types of events, for instance on animate motion (Michotte, 1963, pp. 183-200) and on the "tool function" (Michotte, 1951).

For these and other reasons, Michotte's work is likely to remain of major importance in the psychology of perception.

4.3 Piaget on the perception of causality

Of the large number of studies of perceived causality which have followed the appearance of Michotte's book, only two will be brought up here: Piaget's because it brings in what may seem to be properties of perceptual dynamics, and Natsoulas' because it makes explicit references to mechanics (section 4.4).

Piaget's treatment of perceived causality (Piaget & Lambercier, 1958; Piaget, 1969) differs from Michotte's by giving causality a less narrow meaning. Properties like "resistance", "thrust", "shock", and "contact" (Piaget, 1969, p. 36) are explicitly brought in. He even goes so far as to state in equation form the conditions for causal impressions (1969, p. 237). In addition to the changes of velocity occurring in the two objects, the equation also contains the above four (dynamic?) properties. Whenever the equation is satisfied, true causality should be perceived. Thus the equation is satisfied in launching and entraining situations. Not so in triggering cases, where an unbalance of the equation represents the extra force which is perceived to be driving off the projectile. Piaget also claims that his equation covers some of Michotte's paradoxical cases, which are thereby rendered acceptable as causal percepts. The equation can also handle the increased strength of the causal impression when the projectile velocity is lowered -- a result which, as discussed above (section 4.2.6), was paradoxical to Michotte.

Although it purports to state a relation between the velocity changes of the two objects and some (presumably) dynamic and (presumably) phenomenal properties of a collision event, Piaget's equation does not seem to be an equation in the common mathematical sense. It is more of an abbreviation for a verbal description of various aspects of causal impressions, and the equation form mirrors Piaget's ambition to include the perception of causality under a principle of compensations. Also, there is no attempt at seeking the relations to the properties of real mechanical events. This is surprising indeed, since when working with impressions of something being transmitted from motor object to projectile, or something remaining constant but converted across the collision event, it would seem natural to turn to the science of mechanics to see what is there considered transmitted, constant, etc., in a collision. Piaget's causality equation therefore does not seem to be relevant to dynamic event perception.

4.4 Weight ratio judgments

Natsoulas (1960, 1961) has attempted to relate the basic results of Michotte's to principles of mechanics. In order to do so he first let observers judge the velocity ratio and the weight ratio of the two objects under different conditions of physical velocity ratio and size ratio of the rectangles representing the two objects. In the present context the weight ratio judgments are of primary

interest. They turned out to be dependent on the physical velocities but the dependence was weaker than what would be predicted from our equations (section 3.3.1). Instead, there was a dependence, somewhat stronger in fact, on the size ratios. The latter result agrees with Natsoulas' (1960) expectations, but is at odds with the present analysis, according to which the velocity conditions contain sufficient information about the weight ratios.

The relevance of Natsoulas' (1960) results in the present context is limited, however. The equations for linear collision (section 3.3.1) can be used to predict weight ratio percepts only when the kinematics fulfil the requirements of a linear collision. Unfortunately, in two out of Natsoulas' (1960) five velocity ratios the velocity of the projectile is too high (with u_B and $v_A = 0$, v_B could at most be equal to u_A). Exceeding this limit implies that the projectile gets at least part of its momentum from some other source than the encounter with the motor object. Once that possibility is opened, there is nothing in the kinematics to inform about how much momentum came from the other source and therefore the information about weight ratio is lost. Asking for weight ratio judgments in a series of displays, two fifths of which do not contain any such information, is likely to confuse the observers. For instance, in the triggering cases ($u_A/v_B < 1$) the judgments must be based on something else than the kinematics, and the sizes are perhaps the more likely alternative. Once these are drawn into the judgment process they might also influence the judgments in the true collision cases. The results are therefore not necessarily relevant in the latter cases either, in particular since they also contain the confounding between weight ratio and elasticity which was common in Michotte's studies (section 4.2.1). We may also venture that the shortcomings of the disc method (section 4.2.8) might have more serious effects in quantitative studies.

Using the obtained speed and weight ratio judgments, Natsoulas' (1961) tried to predict the distribution of launching, triggering, and "braking" responses by requiring equality of either "psychological momentum" or "psychological kinetic energy" for the launching response. However, the results need not concern us here because of the inappropriateness of the weight ratio judgments.

4.5 Start events

As already mentioned (section 1.1.1), the Velocity-Seen-as-Such assumption has been shown to be untenable in a series of experiments (Runeson, 1974, 1975, 1976). Instead it was suggested that perception functions according to a Perceptual Concept of Velocity (PCV), which includes or presupposes a natural start.

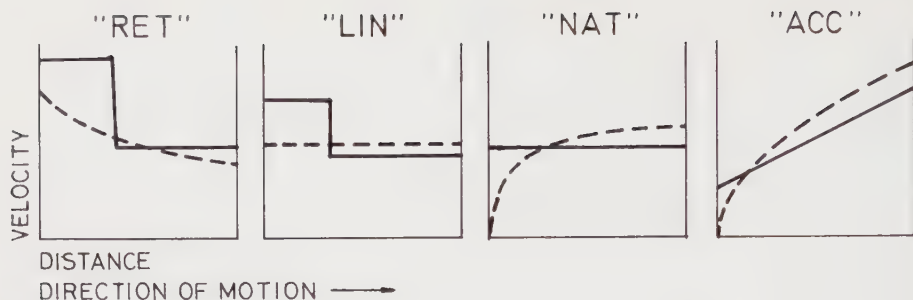


Figure 2. The PCV-phenomena. Broken lines represent physical velocity. Solid lines represent perceived velocity as typically drawn by observers.

The principal results, called the PCV-phenomena, are illustrated in Figure 2, where the broken lines represent the physical velocity functions shown. The solid lines represent typical drawings made by the observers to describe perceived velocity. A certain type of motions, called natural motions (NAT), which begin with a constant acceleration and gradually level off to a constant velocity, are perceived as having a constant velocity throughout. On the other hand, a constant velocity motion (LIN) looks fast in the beginning and later slows down to a lower, constant velocity. A decelerated motion (RET) has a similar appearance, only a bit more dramatic. A constant acceleration motion (ACC) typically seems to start out with a certain speed which is further increased as the motion continues.

The generality of the PCV-phenomena was extended in Runeson (1976), where they were shown to occur also under conditions of strong frame of reference (circle moving partly occluded by an irregular hedge) and when the observer himself triggers the start of the movement. Furthermore, it was shown that the last third or two thirds or the middle third of the track can be occluded without affecting the appearance of the remaining part(s). Thus the PCV-phenomena are neither appearance nor reappearance effects.

To test the possibility that the PCV-phenomena were due to some sort of confusion concerning the meaning of "velocity", the four types of motion functions of Figure 2 were used in a prediction-of-collision task. The movements were occluded halfway or quarterway to an intersection with the track of another, steady and fully visible, movement. The observers judged whether the occluded motion arrived before or after the other one to the intersection. The results agreed very well with the PCV-phenomena. Thus, early occlusion of the constant velocity motion (LIN) led to overestimation of its velocity, whereas late occlusion did not. With the natural motion (NAT) there was no such difference, which confirms that it looks constant all the way (Runeson, 1975).

4.5.1 Perceptual mechanics. In addition to a perceptual concept of velocity, different from the scientific concept, it was suggested (Runeson, 1974) that similar discrepancies might exist for other concepts: time, distance, etc. Together such perceptual concepts could be said to make up a perceptual mechanics. The study of perceptual mechanics, i.e. the establishment of how the perceptual concepts are constituted and how they are related to each other and to the concepts of scientific physics, would be a new type of psychophysics. The essence of it would be the abandonment of the assumption of Physics-Perceived-as-Such.

The biological value of a special perceptual mechanics would be that of informational economy in perception. For example, in a reasonably normal environment, biologically relevant objects or beings follow rather similar nonconstant motion functions when they move off after having been stationary. Such "natural motions" were described above (section 3.2.1; see also section 4.5.3 below). A description of such motions in standard kinematic terms is rather cumbersome. It is much more efficient to take this recurrent type of motion to define a concept of velocity. Since its way of getting started is thereby included in the concept, a movement of this type can in the ideal case be described by one, constant, parameter only. Motions which get started in other ways, through collision or explosion, for instance, would require a more complicated description, but that is a small sacrifice because they are fewer. It might even be appropriate with a complicated description since these are in fact more complicated events, ecologically speaking.

The introduction in the present work of the concept of dynamic event perception represents a more extensive departure from the Physics-Seen-as-Such assumption. It was inspired by the studies of the PCV-phenomena, in particular by the qualitative difference between the start phase and the rest of constant and decelerated motions, reported by many observers, and their reluctance to describe it in velocity terms.

4.5.2 The PCV-phenomena as dynamic events. A reinterpretation of the PCV-phenomena in the dynamic events context would run as follows: The kinematics of the various motion functions observed are first of all taken to contain information about the dynamic properties of the movement. In particular, the first part is taken to provide information about what sort of event it was ("natural" start by moderate force, "explosive" start by large external force, etc.). We therefore first of all perceive what kind of start event occurred. During the later parts of the movements used, the kinematics indicate no events, and velocity might therefore be perceived as such. In other words, "velocity" has little meaning during the first part of the movement, all the more so the more violent is the start event. Later, when no events occur, "velocity" gains

perceptual meaning and is "used" to describe the movement, whether it be constant or undergoing smooth, moderate changes. Notwithstanding, the relation between this meaning of "velocity" and the scientific one is not necessarily simple (see section 2.1).

In the PCV-experiments, however, the observers were neither asked about, nor given means to report, any events. Instead, they were instructed to describe everything in terms of velocity, i.e. to give a kinematic description. Granted that the percept of the start is primarily dynamic (about type-of-event and its properties) there are nevertheless two theoretical possibilities through which a kinematic description could be reached. Either the kinematics are somehow lost in the achievement of the dynamic percept and must therefore be reconstructed. Or the percept does contain a kinematic aspect, which, although often dominated by the dynamic aspects, can nevertheless be attended to with special effort.

The frequently reported difficulty or even meaninglessness of drawing a velocity graph for the first part of motions with a sudden start, and one observer's leaving that portion out of his graphs (Runeson, 1974), would seem to support the first alternative. On the other hand, all observers except one did draw even these motions, and there is a rather good agreement between their graphs. Furthermore, predictions of occluded motion agree with the graphs, and yet there is no evidence of any mental reconstructive activity. On the contrary, the observers found the task meaningful and approached it in a spontaneous way, "trying to see which one came first", and acquaintance with the PCV-phenomena did not alter their percepts (Runeson, 1975). Thus, the evidence does not seem to permit a choice between the two alternatives, and we can conclude only that the velocity descriptions obtained in the PCV-experiments are at least incomplete as descriptions of the percepts because the dynamic aspects are left out.

4.5.3 Smooth starts. The perceiving of the start as an event is obvious when the movement physically starts more abruptly than a natural motion does (e.g. constant velocity motion). Only later does it seem appropriate to talk about its velocity. With natural motions and those starting "slower" than that, on the other hand, speed seems to be perceived all from the start (although not in any simple agreement with physical velocity). This observation raises the question whether it is appropriate to talk about the perception of a start event in these cases, and, for instance, whether there are start events which are "slower" or more gentle than the natural start. To answer the question it is necessary to take a closer look at the physical characteristics of natural motions. Figure 3 illustrates its main features.

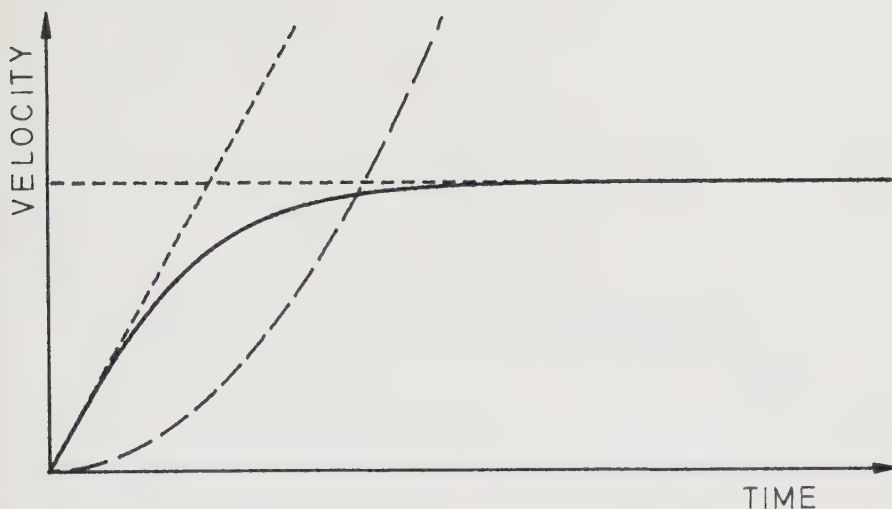


Figure 3. The characteristics of a natural motion.

When graphed with velocity as a function of time it is a curve characterized by two straight lines. One is a tangent representing the initial acceleration and one is an asymptote representing the constant velocity towards which the movement eventually levels off. The degree of abruptness of the levelling off depends on how sharply the resistance increases and/or the available force decreases when velocity goes up. (Although the conditions of a free fall in air or liquid were used in the PCV-experiments, it is not yet known how crucial this factor is.) If we assume that the natural motion in Figure 3 is perceived as having constant speed all the way, a more gentle start would be one in which the acceleration-tangent is less steep. How will such a movement be perceived? Will it look like a more gradual, "slower", start which accelerates all the way from zero velocity? The empirical evidence shows that this becomes the dominating percept only in the most extreme cases, such as "P3" (Runeson, 1974) which has an increasing acceleration (broken curve in Figure 3). The typical response graph in the less extreme cases is the one called "acceleration from an initial velocity" (see "ACC" in Figure 2). This will be taken as evidence for the nonexistence of "gentler-than-natural" start percepts. The rationale for this conclusion lies in the fact that in the basic natural motion function there is a possibly fixed relation between the slope of the acceleration tangent and the level of the levelling-off asymptote.

In Figure 4 the case of a less steep initial acceleration is illustrated. It can either level off to the original asymptote velocity (broken line) or to

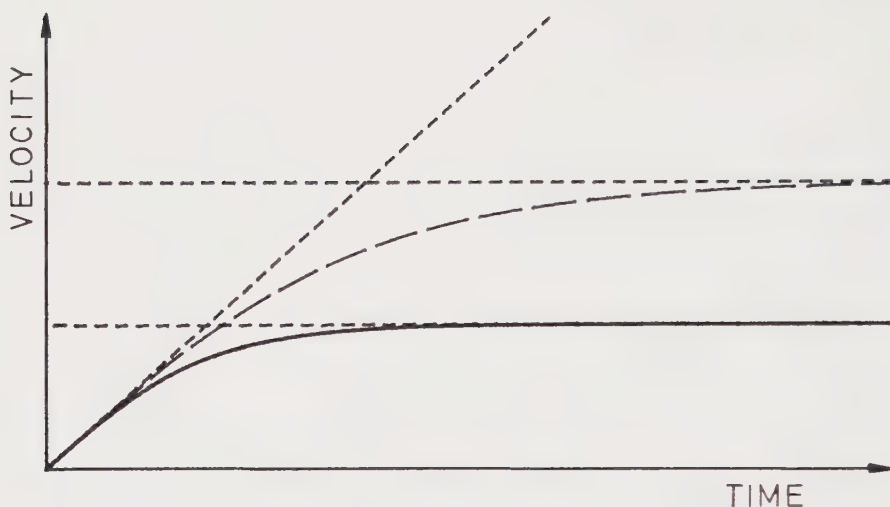


Figure 4. The case of a lower initial acceleration.

one which is correspondingly lower (solid line). Data indicate that the latter case will be perceived as a natural, i.e. constant, motion, which is slower than the original one. The former case, however, is perceived to have a natural start to a low velocity, and after that it begins to accelerate.

The natural start therefore seems to be the limiting case of an event, both in the sense that no start can be perceptually more gentle, and that its conspicuity is down to zero, i.e. it is just the beginning of a motion. Only when the start is made more abrupt than the natural one does it begin to appear as an event and attain conspicuity accordingly.

Note, in conclusion, that the earlier interpretation of the PCV-phenomena, in terms of a perceptual concept of velocity, and the present one in terms of dynamic event perception, are not mutually exclusive. The perception of the start as an event proper occurs only when it is more abrupt than a natural start. Even in those cases there is kinematics enough available in the percepts to make consistent prediction of occluded motion in accordance with the PCV-phenomena.

5 GUIDELINES FOR RESEARCH ON DYNAMIC EVENT PERCEPTION

5.1 Kinematic vs. dynamic approach

The main concern of the present work is dynamics: dynamic events and dynamic features of events, and the perception thereof. This is to be distinguished from perception of kinematics, which is usually intended when speaking about motion perception. Within the study of dynamic event perception a similar terminology can be used to distinguish two possible approaches: the kinematic approach and the dynamic approach.

5.1.1 The kinematic approach. Michotte's work illustrates the kinematic approach to dynamic event perception. In order to produce the intended causal impressions he manipulated the kinematics. Thus, of the many kinematic variables of even a simple event (at least four in a linear collision under ideal conditions) one at a time had to be selected as the independent variable. Furthermore, it was done without knowing very much about what sort, if any, of real events could have produced it. Although the ignorance was not necessary in the linear collision cases (section 3.3.1) it might often be so in other cases, since the equations of mechanics typically work from dynamics to kinematics but frequently are ambiguous or undefined when reversed.

5.1.2 The dynamic approach. The alternative possibility, a dynamic approach, has been implicitly suggested throughout the present work. Superficially it is similar to the kinematic approach in that experiments will typically be made with kinematic displays. This is so because we are primarily interested in the role of kinematically carried information in dynamic event perception. Kinematic simulation techniques are therefore necessary in order to remove non-kinematic cues. The crucial difference lies in how the kinematics are manipulated and what constitutes the independent variables. In the dynamic approach, the independent variables will be dynamic properties of the events simulated. The kinematics will be relevant primarily as an intermediate stage of the technique used to produce the displays.

As can be seen from the equations for linear collision (section 3.3.1) the above distinction stands for a substantial difference in the way experiments are arranged since the relations between kinematic and dynamic variables are of the "one-to-many" type rather than "one-to-one". Thus a change in one dynamic variable leads to changes in more than one kinematic variable, and a change in one kinematic variable represents changes in more than one dynamic variable (or the case does not satisfy the equations).

5.1.3 Reasons for a dynamic approach. As shown in our analysis of the causality perception studies (sections 4.2, 4.3, and 4.4), several of their short-

comings can be traced to the use of the kinematic approach. It has led to the use of stimulus conditions which are a mixture of possible and impossible cases, and, because the experimenters were ignorant about which ones were what, they have sometimes gone astray in their interpretations. Furthermore, there is no question about representativity in these studies, since even when the cases studies are not absurd, they are a peculiar selection. Their value for the understanding of normal dynamic event perception is therefore limited.

Another reason for abandoning the kinematic approach is that the kinematics of even quite simple events are very complicated, especially under normal circumstances of friction, etc. The chances are therefore small that one will ever study a correct simulation of an event. Instead the displays will be more or less incorrect, containing confusing or conflicting information in the kinematics. As discussed above (section 4.2.7) the absence of natural start of the motor object and the equivalent of stopping through friction might have disturbed Michotte's results.

5.1.4 Deviations from possible cases. The recommendation of the dynamic approach does not imply that one must always be confined to cases which are possible according to mechanics. This is for several reasons. One is that scientific mechanics is rather hard to apply to many events of ecological relevance, for instance those involving living creatures. Studies of such events might be hindered inadvertently by a too strict adherence to simple and well-known principles of mechanics. Furthermore, it could be valuable to test the tolerance of the visual system to deviant kinematics and to use -- deliberately -- conflicting kinematic information. Such procedures are probably necessary for an understanding of the principles through which the visual system makes use of available information.

To conclude, there are several reasons for abandoning a pure kinematic approach to dynamic event perception, and to follow a moderate dynamic approach. To let experimentation stay closely related to the mechanics of real events, or at least to keep that relation in sight all the time, is necessary both because the relation of perception to the real world is always a major concern and because it is one major way to keep perception research related to functions of biological relevance.

5.2 "Impossible cases" and the need for restrictions

It must be realized that there are no fundamentally impossible kinematic arrangements. For instance, one can always "solve" a particular case by taking each object to have a built in method of propulsion, and to be very light in relation to that. We have already given one example of a fully possible

"solution" of what Michotte (1963, p. 77) took to be an impossible, and therefore paradoxically perceived, case (section 4.2.6). What Michotte implied was that the moving objects were dead objects, that there was no friction, that no external forces acted upon them, etc. Given that, it was most probably an impossible case. Such analyses, however, are relevant to perception only if the restrictions are reasonably valid in a normal environment. Since event perception should deal with all sorts of events of ecological relevance, including animate events, Michotte's implicit assumptions were obviously untenable.

We may therefore have to face the problem of establishing some sort of a hierarchy of restrictions or decoding principles or preferred percepts, similar to what is done in studies of depth perception. A first candidate for a restriction of this kind was implied in our discussion of Natsoulas' work (section 4.4). It could be expressed: objects are taken to be dead objects as long as the kinematics of the event do not require otherwise. In some of Natsoulas' cases, and Michotte's as well, the conditions of dead-object linear collision were not fulfilled. Only then did the projectile appear to be driven by some extra power, despite that the same solution could have been applied to the normal launching cases as well.

Although the restriction suggested above is only a first guess, reasons could be given for a priority of dead-body restrictions. In a dead-body event the kinematics are very strictly determined. If the kinematics of an observed event fulfil these requirements, it is therefore highly probable that it is in fact a dead-body event. Thus, a discrimination between dead and animate objects could be done quite safely, and that would seem to be of high biological value. It could also be seen as an application of Occam's razor, since the objects in an event are not ascribed any more advanced properties than required.

5.3 The choice of dependent variables

The approach discussion above (section 5.1) concerned the problem of choosing the independent variables in research on dynamic event perception. The choice of dependent variables, on the other hand, might not seem to present any problems since we are by definition dealing with dynamic percepts. When it comes to choosing a particular variable or set of categories, however, there is a great problem. As already discussed (section 1.3.4 above) there is no variable-for-variable correspondence between scientific and perceptual dynamics. It must be left as an empirical problem to find the perceptual categories and variables appropriate for handling dynamic events. Unfortunately, there does not exist any straightforward methods for doing this, but two general criteria will be suggested.

The first one is phenomenological: a basic perceptual property should be readily apprehended in the manner typical of direct perception. The second one is psychophysical: a basic perceptual property should have a clear correspondence to a particular combination of scientific physical properties.

These criteria are reminiscent of Gibson's definition of an affordance (discussed in section 2.5.2) and the second criterion is equivalent to part of his definition. The difference lies in Gibson's use of an ecological criterion instead of the phenomenological one suggested here. Not also that our perceptual categories and variables are real properties of the world by the same argument as that used by Gibson for the realness of affordances. The only difference is that perceptual properties are "taken with reference to" (Gibson, III) the modes of operation of human perception instead of "the nutritive system or the action system or the locomotion system of a given animal" (Gibson, III). The crucial point for the realness of perceptual properties lies in the second criterion, since a combination of real properties is also a real property, at least when the rules of combination can be stated explicitly.

5.4 Two suggested experiments

So far, our treatment of dynamic event perception has been rather abstract. Since it is meant to provide a theoretical framework for an empirical approach, it might be appropriate to terminate the discussion by suggesting two experiments. Although they both concern two-object linear collision, it is not implied that collisions are what dynamic event perception is primarily about. It seems to be a good starting point, however, both because of Michotte's pioneering work on such events (section 4.1 and 4.2), and because our information analysis has shown that collisions are the simplest examples of events in which the kinematics contain sufficient information about object-dynamic properties (section 3.3.1).

Both experiments can be done with the same set-up. It should consist of a good electronic-optic simulation of a two-object linear collision following the formulas in section 3.3.1, with weight ratio (p/q) and damping factor (e) as manipulable independent variables. The simulation should also include friction so that the movements will come to a halt in a realistic way after impact, and the motor object should have a natural start in order to avoid a start event which may be distracting in the perception of the collision event.

Experiment 1 would study the observers' impressions of the weight ratio of the two objects as a function of simulated weight ratio (p/q) under varying conditions of damping (e). The prediction would be that it varies with p/q but not with e . Thus it follows the dynamic approach in the choice of independent

variables. The choice of dependent variable is assumed to be unproblematic in this experiment since weight ratio would seem to be a rare case of variable-for-variable correspondence between physics and perception, at least for the simple task of judging which of the two objects is heaviest. This assumption must of course be questioned if the results of the experiment come out bad or confused, or if the task is phenomenally weird to the observers.

Experiment 2 would be geared to the study of a perceptual variable suggested by some of Michotte's experiments, the "strength of blow" in a collision. Following our discussion above (section 4.2.6), observers should be asked to judge the "strength of blow" while weight ratio (p/q) and damping (e) is varied. The experiment would thus be an attempt at finding the physical correlate of what already seems to fulfil the phenomenological criterion on a perceptual property. Since a functional relation is sought, a quantitative method is necessary. There are reasons to expect an inverted U-shaped relation to the weight ratio, for instance. Note that even if a nice and clean dependence of "strength of blow" on p/q and e is found, there might be other factors, not varied in the experiment, which also belong to the psychophysics of "strength of blow". A possible example is the degree of deformation of the objects during and after the impact (see section 3.3.2). It might be a good idea to include the deformation factor also in Experiment 1, since absence of it might provide conflicting information about the material qualities which are meant to vary with the damping factor (e).

The two experiments suggested represent two basic paradigms that can be foreseen. The first one tests the ability of the observer's perception to pick up a certain property about which information is known to exist in the display (and in real life). It is subject to the limitation that the test is adequate only if the property under study corresponds to a genuine perceptual property and the observers are given proper means and instructions to judge it. Negative results are therefore in principle ambiguous.

The second experiment departs from a phenomenally given dynamic property and tests its dependence on various properties of scientific mechanics. Once such dependencies are reasonably well established it may be of interest to consider the ecological utility of perceiving the property in question, for instance as a guide for action. As a very general hypothesis we may say that the perceptual properties together (the perceptual mechanics) are good in the sense that they allow perception to provide us with quite correct information in adequate form, i.e. in forms which make the information economical and easily applied to the needs of the animal.

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